Gambusia control through the manipulation of water levels in Narawang Wetland, Sydney Olympic Park 2003-2005

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ABSTRACT

Narawang Wetland, a precinct of Sydney Olympic Park, was constructed to provide habitat for the Green and Golden Bell Frog *Litoria aurea*. The Plague Minnow *Gambusia holbrooki* invaded Narawang following flooding soon after the wetland's completion in 2000. Narawang contains 22 habitat ponds, each attached to a water reticulation system. Predation by Gambusia has been identified as a key threatening process for the Green and Golden Bell Frog and may be a major contributor to the disappearance of many frog species in Australia. Its presence in Narawang Wetland offered a unique opportunity for investigation into its management and control. Three groups of ponds in Narawang Wetland were alternately drained in August/October each year between 2003 and 2005. Each year one pond-group was drained and left to dry for four weeks to reduce the population of Gambusia before the onset of breeding by bell frogs. Control of water levels in ponds reduced the Gambusia population. Bell frog tadpoles and metamorphs were observed only in ponds that had been drained and re-filled, however, adult frogs were distributed throughout drained and non-drained ponds. Ongoing monitoring of breeding in Narawang Wetland has shown an increase in breeding activity by bell frogs since the introduction of this program.

Key words: Green and Golden Bell Frog, *Litoria aurea,* Sydney Olympic Park, *Gambusia holbrooki*, pond management.

Introduction

Gambusia, Plague Minnow or Mosquito Fish *Gambusia holbrooki* is a North American fish species introduced to Australia in 1925 with the purpose of controlling mosquito larvae in freshwater systems (McKay 1984). A live bearing species, Gambusia can produce young from late spring to late summer. Identified as a major threat to the breeding success of the Green and Golden Bell Frog *Litoria aurea*, Gambusia is predatory on the eggs, tadpoles and possibly juveniles of the species (NSW NPWS 2003). The Green and Golden Bell Frog has disappeared from 90% of its original range (Pyke and White 2001) and has been listed as an endangered species under the *Threatened Species Conservation Act* 1995 and vulnerable under the *Environment Protection and Biodiversity Conservation Act* 1999. Gambusia is listed as a key threatening process under Schedule 3 of the *Threatened Species Conservation Act 1995*.

Predation by Gambusia may reduce the reproductive success of frog species, particularly in the tadpole stage. Morgan and Buttemer (1996) conducted field and laboratory trials to assess the impacts of Gambusia, and found that bell frog tadpoles were highly susceptible to this predation. Hamer (2002) showed that bell frog tadpoles appear to be naïve to the presence of Gambusia. Pyke and White (2001) identified that the habitats most likely to support a breeding population of bell frogs were free of Gambusia and other predatory fish, however, van de Mortel and Goldingay (1998) observed successful breeding at Coomaditchy Lagoon where Gambusia was present.

Sydney Olympic Park contains 600 hectares of public land located in the geographical centre of Sydney and managed by the Sydney Olympic Park Authority. The Green and Golden Bell Frog was formally discovered at the site in 1993 and since then, 90 hectares of primary frog habitat and 43 hectares of supplementary habitat have been created to conserve the species (Darcovich and O'Meara 2008). Narawang Wetland is one of three primary frog habitat areas and also functions as a floodplain for the adjoining Haslams Creek. The wetland is a 1.6 km constructed corridor covering 20 hectares and consists of 22 habitat ponds and three large water storage ponds. Soon after construction, Gambusia invaded the wetland from Haslams Creek following flooding.

In 2003, Sydney Olympic Park Authority implemented a pond draining program that incorporated approximately 1/3 of habitat ponds in Narawang Wetland each year. This program was designed to drain specified ponds and keep them dry for four weeks in August/September. These ponds would then be refilled by early October with fish-free water. It was expected that a cyclic draining program would reduce the numbers of Gambusia dramatically before the onset of the bell frog breeding season, leading to greater breeding success in the wetland. The aim of this study was to investigate the influence of the draining program on the abundance of Gambusia and to monitor the subsequent breeding of bell frogs.

Methods

Study area

The habitat ponds of Narawang Wetland (Fig. 1) varied in shape, depth and size with the largest pond being 1332 m^2 and the smallest 338 m^2 (average pond size was 852 m^2) (Fig. 2). All had fringing emergent macrophytes of 0.5-2 m width and up to 80% total cover. Dominant macrophyte species were *Baumea reticulata* and *Schoenoplectus validus*. Open water contained submerged herbs such as *Potamogeton sulcatus* and Red Watermilfoil *Myriophyllum verrucosum*. The ponds were situated close together with an average distance of 8 m. The surrounding terrestrial habitat was a grassy sedgeland. Other frog species that have been recorded in the survey area include *Limnodynastes peronii, Crinia signifera, Litoria fallax, Litoria peronii* and *Litoria dentata*.

Water levels in ponds were manipulated by means of a pump located in a sump that was connected to an irrigation system that runs throughout the wetland as part of the site-wide water recycling program.

Pond Management

In August over three years (2003-2005), a selection of the 22 habitat ponds in Narawang Wetland was drained (Table 1). These groups each comprised approximately one third of the wetland and were distributed to facilitate continuous refuge corridors for fauna at all times. Pond selection depended on the reticulation system that groups the ponds into clusters of three. For this reason, a random selection of ponds was impossible but any impact of variables between ponds should have been reduced by the relatively large sample size (7-8 ponds). Order of draining was as follows: August 2003 – ponds 4, 5, 6, 14, 15, 19, 20 and 21; August 2004 – ponds 8, 9, 10, 11, 16 and 17; August 2005 – ponds 1, 2, 3, 7, 12, 13, 18 and 22

Draining of a pond involved the removal of water through a pump located in a sump at the bottom of each pond and usually took one week. The ponds were then left to dry over a 4-week period before fish-free water was reintroduced. A high-pressure reticulation system ensured that Gambusia were not reintroduced to the ponds.

The timing of program implementation was chosen to reduce the potential impact of draining on both frogs and breeding waterbirds. Breeding of bell frogs occurs from spring to autumn, often peaking after heavy rains in January to February (Anstis 2002). Therefore, draining of specified ponds and keeping them dry for four weeks in August/September would avoid the peak frog breeding season and ensure that the Gambusia population was as low as possible for the first half of the breeding season. All ponds were to be maintained at full throughout the frog activity season (September-April) with water provided through the high-pressure reticulation system.

Bell frog surveys

Records were kept of dates, levels of success in drying, weather conditions and other significant events. A fortnightly survey was completed for all ponds with two observers entering ponds to monitor for the presence of tadpoles and juvenile bell frogs and time of reinfestation with Gambusia. Juvenile bell frogs were classified as any frog under the snout vent length of 40 mm. Records were kept of other fauna activity and water levels. Surveys were initiated in September and continued until January of each year.

An auditory survey was held in November and December of 2005 where observers listened for calling males for three minutes, mimicked the call of the male for one minute before listening for a further minute.

Supplementing this information was the bell frog monitoring program (AMBS 2004-6) that included spotlight, auditory and tadpole surveys for frogs at certain times of the breeding season. Spotlight searches and tadpole surveys were conducted at 11 out of the 22 habitat ponds.

Results

The effectiveness of the draining program (Fig. 3) on removing Gambusia from ponds was greatly influenced by weather conditions, pond shape and the quantity of emergent vegetation. This led to the period in which ponds were Gambusia free varying among years (Table 1).

Gambusia

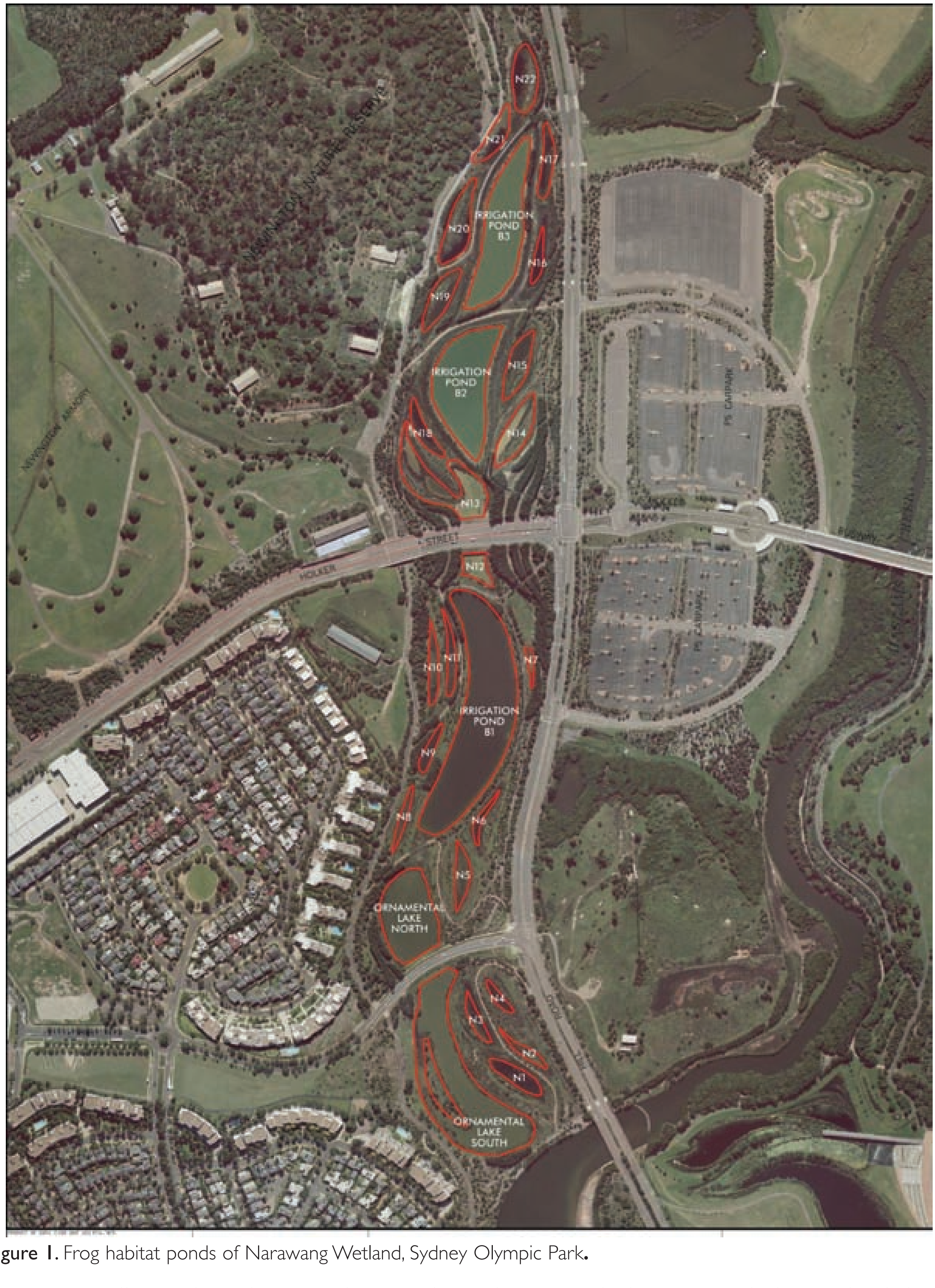
The program for 2002-2003 experienced minimal rain; with each pond dry with cracking mud for the full four weeks. After the ponds were refilled, Gambusia were not observed for an average of 4.5 months. During the 2003-2004 program heavy rains flooded the ponds shortly after the ponds were refilled. Despite this flooding, Gambusia were not observed for an average of 2 months (Table 1). In 2005-2006 there were scattered showers influencing the effectiveness of the draining. Some ponds were never totally empty and some had cracking mud over a three week period. Gambusia were not observed for an average of 3.5 months in the ponds that had been dried.

Apart from 2003-2004 when a flood occurred throughout the wetland, most re-infestations of Gambusia occurred because of mixing of waters between ponds and swales. Over time, slumping of pond edges has meant that Gambusia have had easy access to ponds such as 12, 13, 19 and 22 during high water events. Ponds with no obvious source of reintroduction (e.g. 7 and 8) most likely never became totally fish free, with small Gambusia surviving in the mud and vegetation.

Isolated ponds were observed to remain fish free for longer than those in close proximity to the swales around water storage ponds or infested ponds. Ponds 13, 14, 15, 16, 18, 19, 20 and 21 had noticeable flows from swales during periods of high rain, allowing the early reintroduction of Gambusia. Ponds 1, 3, 5, 6, 7 and 17 are either geographically or topographically isolated, resulting in a delay in reintroduction.

Frog activity

Adult bell frogs were observed in 15 ponds (Table 1), with numbers higher in the northern section of the wetland (ponds 13-22). Observation of adults increased over the three years with the distribution of frogs spreading further into the southern part of the wetland (ponds 1-12) as the project progressed. There appeared to be no relationship between where adult bell frogs were observed and drained ponds.


N22
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N11
N7
IRRIGATION POND B1
N9
N8
N6
N5
ORNAMENTAL LAKE NORTH
N4
N3
N2
N1
ORNAMENTAL LAKE SOUTH

Figure 1. Frog habitat ponds of Narawang Wetland, Sydney Olympic Park**.**

Surveys for calling males only occurred across the wetland in November and December 2005. Ponds 1, 2, 3, 12, 13 and 22 drained ponds had calling males (Table 1). Ponds 19 and 21 also had calling males but were undrained.

Tadpole species observed included *L. aurea*, *Lim. peronii*, *L. peronii*, *L. fallax* and *Crinia signifera*. In each of the three years, the location of tadpoles correlated closely with ponds that were drained (Table 1). In some cases identification of tadpoles to species level was impossible due to the size of individuals. Only two ponds were found to have tadpoles present without being part of the draining program, pond 8 and 13. Observations were made of Gambusia and eels preying on tadpoles.

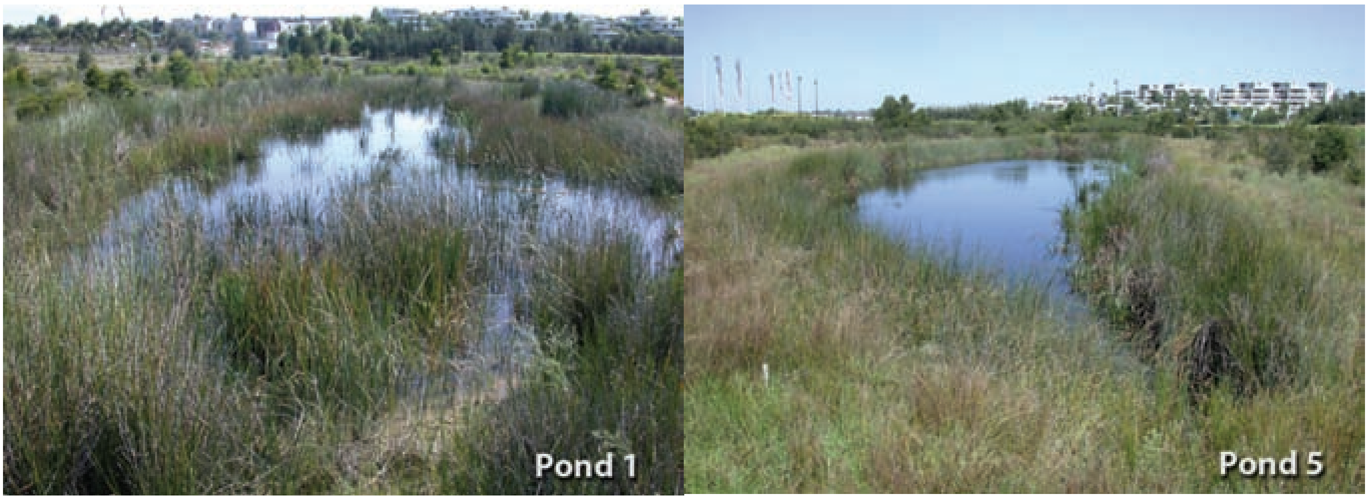

Figure 2. Two ponds in Narawang Wetland showing differences in vegetation distribution and shape.

The number of ponds with juvenile bell frogs increased from 7 in 2003-04 to 12 in 2005-06 (Table 1). In 2003-2004, juveniles were most commonly found in the northern ponds (ponds 13-22). By 2005-2006, numbers had increased dramatically, with juveniles being observed in all parts of the wetland. Ponds that were drained were observed to have higher numbers of invertebrates.

Fortnightly monitoring allowed close regulation of water levels throughout the active frog breeding season (September-April). At all times water levels were maintained above the base of fringing macrophytes.

Year Drained - Pond	Months Gambusia free			Tadpoles			Juveniles			Adult frogs			
	03-04	04-05	05-06	03-04	04-05	05-06	03-04	04-05	05-06	03-04	04-05	05-06	05Calling
2003													
4									J			0.2	
5	5			Tl,p,s,c			J						
6	5			Tp			J		J			0.3	
14	4			Ta			J			0.1	0.1	0.7	
15	4			Ta			J		J	0.3		1.3	
19	5			Ts				J	J	0.3	2.4	2	C
20	5			Ta,s			J	J		0.3	1.2	0.2	
21	5			Ta			J	J	J	0.1	1.2	0.4	C
2004													
8		2		T	Tf								
9		2			Ts			J		0.1	0.3		
10		2									0.1		
11		2								0.3		0.4	
16		2			T			J	J	0.4	1.7	3.8	
17		2			T			J		0.4	1	1	
2005													
1			4		Ts,c	Ta,s,c			J		0.1	0.2	C
2			3			Ts,c			J				C
3			4			Ta,s,c			J			0.3	C
7			4			Ta,p							
12			4						J				C
13			3		Ts	Ts			J		0.3	1.6	C
18			3							0.1	0.2		
22			1			Ta,p,s,c	J		J	0.6	0.8	0.4	C

Table 1. Comparison of Gambusia and frog activity for all habitat ponds in Narawang Wetland drained in one year between 2003 and 2006. Records of tadpoles (T) are shown and indicated by the following where identified: *Litoria sp.(l), L. aurea (a), L. fallax (f), L. peronii (p), Lymnodynastes peronii (s) and Crinia signifera (c).* Records of juvenile bell frogs (J) <40 mm snout/vent length are shown. The number of adult bell frogs (>40 mm) per survey is shown.

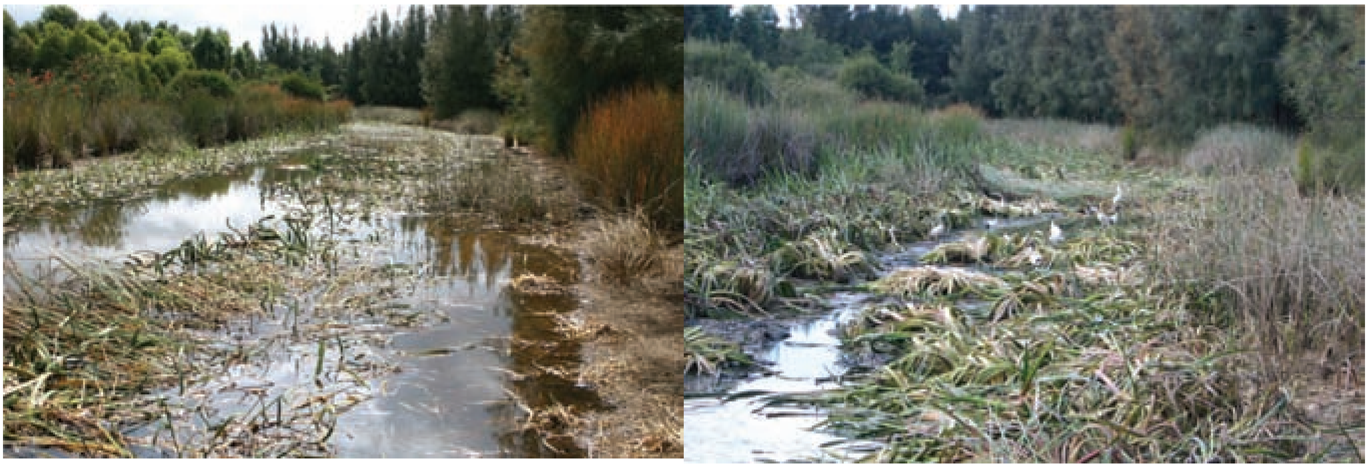

Figure 3. Pond 11 before draining commenced (left) and after (right). Note the presence of birds feeding in the shallows.

Discussion

The ability to manipulate water levels in habitat ponds of Narawang Wetland has resulted in temporary reductions in the population of Gambusia for periods of up to 3 months. This window of opportunity may be important to allow successful breeding of frog species by relieving some of the predatory pressure this introduced fish has on endangered species such as the Green and Golden Bell Frog.

Draining

Weather conditions each year influenced the ability to control water levels. For example, rainfall in 2004 resulted in the flooding of the whole wetland, reintroducing Gambusia early to all ponds. Some operational difficulties included regular pump repair due to the presence of eels and sediments trapped in the sumps of ponds. The influence of pond size, shape and vegetation cover impacted on the extent to which drying was successful. For large ponds such as 12 and 13, a longer period than 4 weeks was required for effective drying.

Gambusia

Drained ponds remained free of Gambusia for an average of 3 months, perhaps allowing greater numbers of tadpoles to survive to metamorphosis. Ponds 8 and 13 were the only ponds to have tadpoles when not drained. During 2004-2005, pond 8 periodically became dry due to leaks and therefore the Gambusia population remained low. The record from pond 13 was that of a single *Lim. peronii* tadpole.

Once the fish was found to be present again in ponds, numbers quickly increased. By the end of the monitoring period (January), the population density of Gambusia appeared to have returned to pre-drainage levels.

The reintroduction of fish during this study was mainly from the flow of contaminated water between infected and 'clean' ponds. Design of wetlands for frog habitat should include ponds that are divided by levee banks or located apart so the movement of fish such as Gambusia can be controlled, yet still facilitate the movement of frogs. Due to the size and complexity of Narawang Wetland and the potential for recolonisation from Haslams Creek during flooding, it is unlikely that Gambusia will ever be eliminated. However, the benefit of 'resting' ponds appears to be considerable.

Frogs

Monitoring of the 3-year draining program has shown a correlation between increased indices of frog breeding and ponds that have been recently drained. Drained ponds showed high occurrences of tadpoles, juvenile frogs and calling males.

The bell frog monitoring program detected an increase in sightings of adults over 2004-2006. There were significantly (30%) more sightings of adult bell frogs in 2004-05 than in any other season since monitoring began in 2001 (AMBS 2005). Spotlight surveys for 2005-2006 indicate that juvenile activity also increased.

Evidence of breeding by bell frogs coincided with the draining program. The relative abundance of bell frogs in Narawang Wetland in 2004-2005 and 2005-2006 was the greatest recorded in this precinct since monitoring started. Significantly more adults and juveniles were observed and Narawang Wetland was the only primary frog habitat at Sydney Olympic Park that showed an increase in juvenile abundance during 2005-2006. Monitoring suggests that the increased number of juveniles was the result of an increased level of frog breeding (AMBS 2006). Further monitoring is required to demonstrate this conclusively.

There is a strong link between tadpole observations and drained ponds from which it can be assumed that the control of water levels has increased the breeding opportunities for bell frogs. This is an important step towards managing bell frog habitats at Sydney Olympic Park.

Draining selected ponds within a wetland may assist breeding activity by meeting other habitat requirements of bell frogs. Pyke and White (1996) assessed bell frog habitats across NSW and found that breeding was more likely to occur in ponds without predatory fish and that showed ephemerality. Certainly, draining will reduce the density of predators and competitors (e.g. fish, eels or other frog species).

Morgan and Buttemer (1996) suggested that greater survival of tadpoles in the presence of Gambusia may be assisted by pond weed providing shelter. van de Mortel and Goldingay (1998) observed successful breeding of bell frogs in the presence of Gambusia in a water body with dense submerged vegetation. Ponds in Narawang Wetland contain a wide variety of submerged and emergent water plants. Pyke and White (2000) suggested that bell frogs may be able to coexist with Gambusia if there was a low ratio of fish density to frog density, more shelter is available for tadpoles and adequate alternative food is present for the fish. These aspects of pond ecology will need to be investigated in Narawang Wetland to assist the development of effective management strategies for Gambusia.

From a habitat management perspective, the draining of ponds has provided opportunities for improved vegetation management. The sensitive nature of the wetlands as habitat for a protected species prohibits the usual application of herbicide and many horticultural practices. The manipulation of water levels for the control of Gambusia and the maintenance of frog habitat provides an opportunity for more intense weed removal, including the spraying of herbicide, planting or thinning of macrophytes, because it reduces frog habitat in a localised area for a period of four weeks.

Management of frog habitat areas must be a dynamic and adaptive process, allowing for changes in management actions over time in response to changing circumstances. More investigation will need to be undertaken before the actual impact of water level manipulation and Gambusia predation on tadpoles is better understood. This study is the first step in providing information that will assist land managers in the design of habitat ponds for frogs and in the management of predatory fish such as Gambusia.

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